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# Assessing the deterrence value of carrier presence against adversary aggression in a coalition environment

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# NAVAL POSTGRADUATE SCHOOL

**MONTEREY, CALIFORNIA**

# THESIS

**ASSESSING THE DETERRENCE VALUE OF CARRIER PRESENCE AGAINST ADVERSARY AGGRESSION IN A COALITION ENVIRONMENT**

by

Roger L. Huffstetler

September 2017

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The aircraft carrier serves as the centerpiece of the U.S. Navy's carrier strike group (CSG), providing combatant commanders with immediate options for power projection and sea control. In times of crisis, the U.S. Navy must decide whether or not to send a CSG to an area to deter aggressive enemy action and maintain regional stability. This thesis seeks to quantify the deterrence value of a CSG using a game-theoretic framework. Consider a region with several nations, where two major players stand out: Blue and Red. The two players deploy limited forces and strengthen their positions by seeking alliances with the other nations in the region. We develop a Markov game to model the interactions between the two players and these other nations over a period of time. The game starts in Notional Operation Plan Phase 1 and continues until either player chooses to enter Phase 0 or Phase 2. From Blue's standpoint, we define deterrence as the probability that Red will choose to enter Phase 0. In a case study based on a crisis in South China Sea, we find that quickly deploying forces and establishing diplomatic advantage are equally important in deterring aggression.

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**ASSESSING THE DETERRENCE VALUE OF CARRIER PRESENCE AGAINST ADVERSARY AGGRESSION IN A COALITION ENVIRONMENT**

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Submitted in partial fulfillment of the
requirements for the degree of

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# ABSTRACT

The aircraft carrier serves as the centerpiece of the U.S. Navy's carrier strike group (CSG), providing combatant commanders with immediate options for power projection and sea control. In times of crisis, the U.S. Navy must decide whether or not to send a CSG to an area to deter aggressive enemy action and maintain regional stability. This thesis seeks to quantify the deterrence value of a CSG using a game-theoretic framework. Consider a region with several nations, where two major players stand out: Blue and Red. The two players deploy limited forces and strengthen their positions by seeking alliances with the other nations in the region. We develop a Markov game to model the interactions between the two players and these other nations over a period of time. The game starts in Notional Operation Plan Phase 1 and continues until either player chooses to enter Phase 0 or Phase 2. From Blue's standpoint, we define deterrence as the probability that Red will choose to enter Phase 0. In a case study based on a crisis in South China Sea, we find that quickly deploying forces and establishing diplomatic advantage are equally important in deterring aggression.

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# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| CSG | carrier strike group |
| DIME | diplomatic, information, military, and economic |
| EEZ | exclusive economic zone |
| GDP | gross domestic product |
| GF | Global Firepower |
| NPS | Naval Postgraduate School |

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# EXECUTIVE SUMMARY

The U.S. Navy's Carrier Strike Group (CSG)—which comprises the aircraft carrier, the associated air wing, surface combatants, and support ships—represents the Navy's largest and most powerful combat system. However, the CSGs also account for the largest procurement, operating, and support costs. To justify the cost of, and necessity for, these powerful and expensive weapons systems, it is important to understand how the CSGs help the U.S. Navy achieve its mission, which includes deterring aggression and maintaining freedom of navigation. When tension rises in a region and freedom of the seas is threatened, how effective are the CSGs at deterring aggression? This thesis seeks to answer this question.

We develop a game-theoretic model to study how the presence of a CSG helps deter aggressive military action of opposing forces and maintain regional stability. Consider a geographical region where tensions rise and the escalation threatens regional stability. Several nations in the region seek gain through diplomatic, information, military, and economic means. Two nations stand out: a global power and a regional power. These two nations are the active players in our game-theoretic model. In order to achieve their respective goals, these two players deploy limited military forces to the operating area and seek alliances with the other regional nations to strengthen their position. The actions of the other nations in the region are modeled by random events. We adopt the framework of a Markov game to model the interactions between these two players and the other regional nations over a period of time, until the tension either escalates to a full-blown war or deescalates back to peacetime.

We conduct a case study in the South China Sea to demonstrate our model. The U.S. represents the global power, while China represents the regional power. The other nations in the region include the Philippines, Vietnam, Taiwan, Singapore, Malaysia, and Indonesia. The U.S. can send up to three CSGs to the South China Sea area, while China can send forces comparable to two U.S. CSGs. Both the U.S. and China make diplomatic moves to form alliances with the other nations in the region. The scenario begins in Notional Phase 1, and ends when the tension escalates to Phase 2, or deescalates to Phase

0. If it is China who decides to deescalate to Phase 0, then the presence of CSGs successfully deters China's aggression and maintains regional stability.

The case study provides several key insights into how CSG presence and diplomacy in the region affect U.S. objectives.

1. CSG presence, coupled with strong diplomatic advantage, provides the most effective means of deterring aggressive enemy actions. In some cases, CSG presence alone was unable to deter. By adding regional nations into its alliance, the U.S. increases the probability that CSG presence deters opposition forces.

2. During deterrence operations, it is critical for the U.S. to act quickly to build strong diplomatic alliances and CSG presence in the region. The deterrence value of CSG presence becomes weaker after China moves forces into the region.

3. During peacetime operations, while attempting to shape the regional environment, the U.S. should build strong diplomatic ties with the regional nations. Strong diplomatic ties are critical for the U.S. to quickly form military alliances with other nations, which amplifies the deterrence value of CSGs.

4. In some instances, the U.S. should seize the initiative and escalate to Phase 2, when they have a force advantage and a diplomatic advantage, before China has a chance to increase its force presence.

5. Model output is sensitive to key input parameters such as the military strength and size of each regional nation's economy, as well as the probability that each regional nation will join the alliance of a player. Effective intelligence and assessment which accurately reflects these input parameters is essential to properly analyze and interpret the model's output.

Our case study uses open source data and subjective assessment to define the input values. Subject matter expert opinion or intelligence estimates could provide better resources to assess model parameters. Additionally, our model assumes that both players simultaneously make decisions without knowing the other's move. It would be interesting to assess the value of intelligence, if one player learns about the other player's move before deciding his own move. Another possible extension is to allow three or more active players in the game.

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# I. INTRODUCTION

The allocation of a military budget is a difficult problem to quantify. Military budgets are often perceived as buying down risk. The risk incurred for failing to procure an aircraft, ship, or weapons system manifests itself in a loss of strategic positions, global instability, or combat losses. The intangible nature of strategic positioning and global stability are often rolled into the responsibility of military presence. In Joint Publication 5–0, "Joint Planning," the Joint Chiefs of Staff (2017) define risk as "the probability and consequence of loss linked to hazards." Specific to the Navy, the largest single procurement and sustainment cost is the presence of our aircraft carriers, the associated air wings, and the ships that make up the Carrier Strike Group (CSG). There is constant pressure to better understand the value of the CSG in terms of both peacetime and combat missions. Combat losses are calculated using multiple simulations, from physics level models to complex campaign simulations. However, the probability that a conflict will occur, the other side of the risk product, is often overlooked. Naval Officers often make risk calculations in their head, such as, "Do I takeoff in this weather?" or "Should I investigate the ship we are approaching?" This culture makes risk calculation a part of a Naval Officer's decision making process. However, the attempt to quantify a difficult side of the risk calculation, the probability of conflict, is often seen as intangible, considered impossible, or is ignored. An imbalanced approach to risk management, which places a greater emphasis on the severity of losses, can minimize investments to maintain military presence that prevents conflict. One possible way to deter potential conflict is for the U.S. Navy to send a CSG to the area. This thesis seeks to quantify the value of presence, and the associated impacts on deterrence, to inform resourcing decisions and enhance warfighting risk calculations.

To maintain stability around the globe, the Navy operates forward, offering presence and quick reaction combat capabilities. Forward deployed naval forces influence both sides of the risk calculation by providing deterrence through presence, which reduces the probability that a conflict will occur and the consequence of combat operations. The consequence of combat operations can be considered both in terms of

failing to meet objectives, as well as, combat losses. Joint doctrine (Joint Chiefs of Staff 2017) often separates these two different risk calculations as "Risk to Force" and "Risk to Mission." Our model assumes the objective of the combat operations are constant and therefore focus on the "Risk to Force." Within the construct of the model, the choice of forces is simplified into the allocation of forces, which include the CSG. In "A Design for Maintaining Maritime Superiority" (United States Navy 2016), the Chief of Naval Operations charts a design and future course for the U.S. Navy to achieve goals established in the revised cooperative maritime strategy (United States Navy 2015). Admiral Richardson highlights the requirement for deterrence, and combat if necessary, when he states the mission of the U.S. Navy as:

> The United States Navy will be ready to conduct prompt and sustained combat incident to operations at sea. Our Navy will protect America from attack and preserve America's strategic influence in key regions of the world. U.S. naval forces and operations—from the sea floor to space, from deep water to the littorals, and in the information domain—will deter aggression and enable peaceful resolution of crises on terms acceptable to the United States and our allies and partners. If deterrence fails, the Navy will conduct decisive combat operations to defeat any enemy. (United States Navy 2016)

When escalating tensions present a risk of conflict, the U.S. Navy must decide whether to send forces into the area to maintain regional stability and deter aggressive military actions. Often the force of choice is one or more CSGs. Limited resources and high operating costs can be deciding factors in whether a CSG is deployed to the area. Determining the number of CSGs to sustain in the military force is a key component of the U.S. Navy's proposed 355 ship navy.

## A. RESEARCH GOALS

The goal of this thesis is to develop a game-theoretic model to study the deterrence value of a CSG against an adversary's aggression. Consider a geographical region where several nations have disputes over an issue, such as island ownership or exclusive economic zone (EEZ) rights. Tension within the region rises and the escalation threatens regional stability. There are several nations in the operational theater, but two nations stand out. One nation is a regional power and the other is a global power. These

two nations seek gain through the instruments of national power, namely diplomatic, information, military, and economic (DIME). The global power and regional power can deploy limited forces to the area.

Our research attempts to answer the following question: What is the deterrence value of the global power's CSG against the regional power's aggression? To answer this question, we develop a Markov game model for the global power and the regional power as two active players. These two players act selfishly to achieve their respective goals. The actions of the other less powerful nations in the region are modeled by random events. Each player can seek alliance with these less powerful nations to strengthen its position in the region. The alignment of nations is often dependent on the geographical objectives, economic relations, or even historical ties. Further, we apply sensitivity analysis to determine the range of values through different situations to include regional alliances and varying levels of presence.

The two players are assumed to be rational actors that attempt to maximize their respective utility. The utility for each nation is based on the combination of several metrics related to DIME factors. A nation's diplomatic value concerns its ability to persuade the other nations to advocate or vote for a common cause, or to form a military alliance. The information value is a nation's ability to find out the other nations' perceived positions on issues, military capabilities, information value, and economic value. Military value quantifies the size and quality of a nation's military force and represents the ability to achieve military objectives. The economic value specifies the size of a nation's economy, in terms of gross domestic product (GDP), and its ability to use trade to affect the economy of the other nations.

In Joint Publication 5–0, the Joint Chiefs of Staff (2011) describe the phases of combat, which range from Phase 0 to Phase 5. Phase 0 is described as the shaping phase and is considered normal peacetime operations. Phase 1 is considered the deterrence phase and marks the beginning of a conflict with belligerents moving forces, relaxing rules of engagement, and initiating conflict. Phase 2 is often considered the beginning of kinetic warfare. Additional information and definitions for the phases of conflict can be found in the Joint Chiefs of Staff (2011). The Markov game begins in Phase 1, and

proceeds by rounds. The game ends when there is a transition to Phase 0 or Phase 2. If the presence of the global power's CSGs influences the regional power to transition into Phase 0, then deterrence is successful and a major international crisis is resolved. Otherwise, deterrence fails, and further military actions may be needed in Phase 2. Our focus is to use the model to inform how the presence of CSGs affect the probability that the regional power will choose to transition to Phase 0 to avoid further military conflict.

We adopt the framework of a Markov game to develop our model between the two players. A Markov game is a game that involves a sequence of moves, similar to Monopoly, where the outcome of the game depends upon the player's move and some random event. In our context, the game proceeds in rounds. Each player decides among several actions in each round, and their actions together, with some random events, determine the state in the next round. Readers interested in the theory of Markov games are referred to Washburn (2014).

## B. RELATED WORK

The following studies help frame our research and analysis. The first two studies assess the value of deterrence based upon the use of police force presence and how it affects criminal activity. The last study reviews the design and results of a wargame conducted in the South China Sea between the U.S. and China.

It is necessary to have a working definition for the meaning of "deterrence." We adopt the definition from the Joint Chiefs of Staff (2010), which defines deterrence as "the prevention of action by the existence of a credible threat of unacceptable counteraction and/or belief that the cost of action outweighs the perceived benefits." Additionally, we define the meaning of "presence" within the context of this thesis. We say that a CSG demonstrates presence when it is located within the geographical region and able to provide striking power. The striking power of the CSG can vary based on the objectives, amount of forces required, and duration of the strikes. Typical ranges of the influence vary from 300 nautical miles to over 1000 nautical miles. Virtual presence, or presence cited as future deployments or residuals of recent visits cannot provide any striking power. We consider virtual presence to represent no presence at all.

Sherman (1990) examines the deterrent effects of police presence through the use of crackdowns, which threaten apprehension and sanctions for specific criminal offenses. Based on case studies, he noted long term crackdowns exhibit initial deterrence which quickly subsides and offers little residual deterrence once the crackdown has ended. Sherman observes that, in most cases, increased presence and threat have little effect on criminal activity once the effect of initial deterrence erodes. His study suggests that the most effective deterrence may arise from shorter presence spread across multiple locations.

Barnes and Kleck (2014) examine whether or not larger police presence provides a greater deterrence to criminal offenses. Their research found no link between presence and the perception of risk, suggesting that increases in the number of police officers will have little effect on crime. Further, they assert that a decrease in police officers will not result in an increase in the number of crimes committed.

Akin et al. (2017) conducted a wargame to study the actions and outcomes of carrier presence in the South China Sea. The wargame team examined a scenario involving several nations within the same geographical region. The United States represented the global power, while China represented the regional power. Six nations in the South China Sea were chosen to act as the regional nations. The nations were Vietnam, Taiwan, the Philippines, Singapore, Indonesia, and Malaysia. Each of these nations sought to exploit the full range of DIME tools to produce a favorable outcome.

The wargame examined three primary issues. First, it examined the interaction between the global power and the regional power in Phase 1, as well as, any interactions that contributed to the situation transitioning out of Phase 1. Second, the wargame explored how the smaller regional nations effected the interaction between the global and regional power, and the resultant effect on the regional environment. Third, the wargame sought to validate viable courses of action for each nation player within the DIME construct.

The main wargame objective for the United States and China was to minimize cost throughout game play, while simultaneously attempting to achieve specific country

objectives. The United States' specific objective was to maintain regional influence and freedom of navigation within the South China Sea. China's objective was to increase regional influence and expand or claim territorial rights. Regional nations were tasked to take diplomatic and economic action necessary to increase individual country prosperity.

The wargame did not capture the impact of a transition to the Phase 2 environment. Although the wargame allowed for a transition to Phase 2, no player action resulted in a shift out of Phase 1. Further, CSG presence in the Phase 1 environment had minimal effect on player decisions, as only minor advantages were realized for the U.S. players. Post-wargame surveys revealed that often the advantages offered by CSG presence did not justify the player's perceived risk to the CSG as tensions increased.

The regional nation players viewed economic incentives from the U.S. and China as strong influential measures. Bilateral military exercises were also viewed favorably. Actions taken by the U.S. and China that resulted in an escalation in tension were viewed negatively, while action taken by the main players to deescalate tensions elicited a positive response from the other nation players.

## C. BACKGROUND OF THE CARRIER STRIKE GROUP

The nuclear-powered aircraft carrier is the predominate representation of United States military might. Its presence has been used to demonstrate American resolve, display commitment to the defense of our allies, and to maintain regional stability. Aircraft carriers provide our political and military leadership with a number of immediate response options. In the Lexington Institute's study, "Aircraft Carriers: The Unique Value of America's Most Famous Combat System," Thompson (2016) describes the importance of aircraft carriers, and the CSG, to our combatant commanders. He asserts that their ability to project power with a large complement of aircraft and to perform a wide variety of missions make them an invaluable resource for our military forces and strategic goals.

> Carriers are in continuous demand from regional commanders. Because the 60–75 aircraft in carrier air wings can perform a diverse array of military functions from sustained strike warfare to counter-terror

> operations to reconnaissance missions, carriers are in continuous demand from regional combatant commanders. (Thompson 2016)

The U.S. aircraft carrier serves as the centerpiece of the Navy's CSG, which comprises several surface combatants whose composition is dictated by various mission requirements. A CSG is generally composed of the same types of ships. These ships include the aircraft carrier and its carrier air wing, guided missile cruisers, guided missile destroyers, a fast attack submarine, and logistical support ships. The CSG can be deployed in a variety of roles including the protection of shipping, forward presence, deterrence, sea control, humanitarian assistance and disaster relief, and power projection.

Over the last two decades, our commitments and responsibilities around the globe have increased, while the number of operational CSGs has declined. Given the high cost to build, operate, and support, as well as, the technological advancement of anti-access and area denial weapons by our adversaries, the future necessity and role of the aircraft carrier, and its air wing, has been questioned. Can the presence of the CSG effectively deter enemy aggression?

Since its introduction to the U.S. Navy, the aircraft carrier has served in a number of roles in the fleet supporting military operations. In an article written for the *Naval War College Review*, Rubel (2011) suggests a number of doctrinal roles that the U.S. aircraft carrier has filled throughout its use in the fleet. He asserts six specific roles based on their historical use. Rubel (2011) defines these roles as the eyes of the fleet, cavalry, capital ship, nuclear strike platform, airfield at sea, and geopolitical chess piece. He proposes the following description for each of these roles. As the fleet's eyes, the carrier launches aircraft which scout and report enemy locations and movement. In the doctrinal role as the fleet's cavalry, the aircraft carrier moves into dangerous locations, conducts quick strikes against the enemy, and moves to a safe distance. As a capital ship, aircraft carriers stay on station and fight, similar to 18$^{th}$ century ships of the line. The nuclear strike platform launches nuclear capable bombers to strike strategic targets. As an airfield at sea, the carrier supports ground forces by projecting power and sustaining air superiority. Finally, in its role as a geopolitical chess piece, the carrier is used by American political leadership to reassure our allies and stand ready to respond to any world crisis.

Rubel (2011) contends that the doctrinal roles of the airfield at sea and as a geopolitical chess piece are predominantly how we observe U.S. aircraft carriers utilized today. For example, during the Korean and Vietnam wars, U.S. aircraft carriers operated off the coast of these nations as an airfield at sea, enabling a steady flow of combat strike and ground support missions. At the outset of Operation Iraqi Freedom, aircraft carriers provided precision strike capability from the sea while overflight permission and basing rights were still being negotiated. As a geopolitical chess piece, aircraft carriers sailed through the Taiwan Strait in 1996 to reassure our allies and demonstrate our commitment to the defense of Taiwan. More recently, CSGs were deployed to the Pacific in response to North Korea's ballistic missile tests.

## D. THESIS OVERVIEW

Chapter II introduces a Markov game designed to model the interaction between nations in a region when tension escalates and there exists the likelihood of combat. Two nations that stand out—a global power and a regional power—are modeled as players in the game. These two players deploy limited forces and strengthen their position by seeking alliances with the other nations in the region. The game starts in Phase 1, and ends when either player enters Phase 0 or Phase 2.

Chapter III demonstrates the Markov game model, via a case study, based on a scenario in the South China Sea. In 2020, tension escalates in South China Sea as a result of disputes over ownership of islands and EEZs. The global power is the United States and the regional power is China. We use open-source data to estimate model parameters, and analyze how the United States can use CSGs to deter China's aggression.

Chapter IV concludes this thesis. We discuss the lessons learned, assumptions and limitations of the mathematical model, and future research directions. In particular, we discuss the pros and cons of our approach based on a Markov game model with another approach based on a wargame.

# II. A MARKOV GAME MODEL

This chapter describes a Markov game model between Blue and Red to assess the probability that Red will choose to escalate to Phase 2 or deescalate to Phase 0 based on perceived rewards. The game is nonzero-sum, and proceeds in rounds. Each player computes reward through military and economic gains. In each round, each player adopts its prudential strategy, which maximizes its own expected payoff by assuming the opponent's goal is to minimize it. Hence, the payoff to each player is its security level, a guaranteed level of reward assuming the worst possible action from its opponent.

## A. MATHEMATICAL MODEL

We consider an operational theater that involves several nations, states, or groups. Tensions escalate due to disputes among these nations threatening the stability within the region, and possibly the world. Disputes can arise over ownership of an island, the development of aggressive military capabilities, trade inequalities, or other friction points.

There are several nations in the operational theater, but two nations stand out. One nation is a global power (Blue) and one is a regional power (Red). Blue ($B$) may be able to deploy zero to three CSGs to the area, at an increasing cost, while Red ($R$) only has the military force equivalent of two CSGs. We develop a Markov game played by these two players.

Besides Blue and Red, there are several other nations in the region, denoted by the set $S$. Suppose there are $n$ such nations, so $|S| = n$, and we enumerate these nations $1, 2, \ldots, n$. We use "players" to refer to Blue and Red, and "nations" to refer to those in $S$. During the game, the Blue and Red players interact with these nations. The choices of the nations in $S$ are modeled by random events. At the beginning of the game, all nations are considered neutral, in other words, they are not in an alliance with the Blue or Red player. They can choose to remain neutral, join the alliance of Blue, or join the alliance of Red. Blue and Red denote active decision makers seeking to maximize their respective expected reward accumulated throughout the game. Between player $i$ and nation $j$, we

quantify the diplomatic tie by $d_{ij} \in [0,1]$, for $i = B, R$ and $j \in S$. A value close to 1 indicates nation $j$ is friendly with player $i$, while a value close to 0 indicates nation $j$ is hostile towards player $i$. If $d_{ij} = 0.5$, then nation $j$ does not have a favorable or unfavorable impression of player $i$. The value of the diplomatic tie for each nation is set at the beginning of the game and remains unchanged.

The size of the Markov game's state space depends on three factors, the number of Blue forces, the number of Red forces, and the number of regional nations in the set $S$. The number of Blue and Red forces range from zero up to their respective maximum force size. During the game, each nation has three possible choices, namely, join Blue's alliance, join Red's alliance, or remain neutral. Therefore, the number of possible diplomatic alliances is given by $3^n$, where $n$ is the number of nations. The game's current state is given by the number of Blue and Red forces in the operating area and the current diplomatic alliances.

The game starts in Phase 1, and proceeds by rounds, and ends when one player escalates to Phase 2 or deescalates to Phase 0. During the game, the state at the beginning of each round is delineated by $s \equiv (x_B, S_B, x_R, S_R)$, where $x_i$ is the force size deployed to the area by player $i$, and $S_i \subseteq S$ is the set of nations that join the alliance of player $i$, for $i = B, R$. Each state $s$ has two additional mirror states, corresponding to Phase 0 and Phase 2, respectively. Write $\Omega_0$, $\Omega_1$, $\Omega_2$ for the sets of states in Phase 0, Phase 1, and Phase 2, respectively. Once the game enters a state $s \in \Omega_0 \cup \Omega_2$, the game ends and player $i$ receives a final playoff $V_i(s)$, for $i = B, R$. If the state is $s \in \Omega_1$, then the game continues and each player will make separate decisions, and their actions together will guide the evolution of the game. For $s \in \Omega_1$, each player will choose an action from its pure strategy set.

If a player chooses to act diplomatically, it attempts to persuade one of the neutral nations to join its alliance. The set of neutral nations is $S \setminus (S_B \cup S_R)$. For nation $j \in S$, player $i$ needs to spend $c_{ij}$ for this action. If player $B$ (or $R$, respectively) acts on nation $j$ while player $R$ (or $B$, respectively) does not, then there is a probability $d_{Bj}$ (or $d_{Rj}$, respectively) that nation $j$ joins the alliance of player $B$ (or respectively, player $R$),

and probability $1 - d_{Bj}$ (or respectively $1 - d_{Rj}$) that nation $j$ will stay neutral for another round. If both players, $B$ and $R$, act on nation $j$, then there is a probability $d_{Bj}\,(1 - d_{Rj})$ that nation $j$ joins the alliance of player $B$, and probability $d_{Rj}\,(1 - d_{Bj})$ that nation $j$ joins the alliance of player $R$, or otherwise nation $j$ will stay neutral for another round.

If a player chooses to make a military move, it increases its force presence to the next level. The cost for player $i$ to do so is $a_i$, for $i = B, R$. There is a maximum level of military presence for each player. There is also a fixed cost to maintain the force level, which is $b_i$ for each additional level for each round. For example, if player $B$ currently has force presence at level 2, then in order to maintain that level for 3 rounds, the cost is $b_B \times 2 \times 3$.

We assume that in each round, the two players make their decisions simultaneously. In other words, each player makes the decision without knowing that of the other, and they reveal their choices at the same time. Their joint decision—together with random events whether the nations join their alliance—determines the next state. At the end of a round, both players find out about the other's move, and then they both learn about the new state.

In each round, either player can take a move to end the game. There are two ways to end the game. Either player can unilaterally choose to enter Phase 0 or Phase 2. Once the game ends in state $s \in \Omega_0 \cup \Omega_2$, player $i$ gets a final payoff $V_i(s)$, for $i = B, R$. If one player decides to enter Phase 2 while the other decides to enter Phase 0, then we assume that the game enters Phase 0 and ends. The goal of each player is to maximize the expected total payoff, reward less cost, accumulated throughout the game.

During the game in Phase 1, each player can only increase its force presence, but not decrease it. Additionally, once a nation joins the alliance of either player, that nation will remain faithful to that player throughout the game. Therefore, once the game leaves a state, the game will never reenter that state. This property makes it possible to compute the value of each state recursively, starting with states whose only viable action for a player is to enter Phase 0 or Phase 2.

For each state $s \in \Omega_1$, there exists a pair of values $V_B(s)$ and $V_R(s)$ that represent the expected payoffs for the two players, respectively, if both players play their respective optimal strategy from that point on. Given the values $V_B(s)$ and $V_R(s)$, for $s \in \Omega_0 \cup \Omega_2$, the goal is to compute $V_B(s)$ and $V_R(s)$ recursively for $s \in \Omega_1$.

## B. PAYOFFS FOR STATES IN PHASE 0 AND PHASE 2

For each state $s \in \Omega_0 \cup \Omega_2$, we can use subject matter experts to assess the final payoff $V_B(s)$ and $V_R(s)$ for the two players. To facilitate model demonstration, we compute the final payoff in Phase 0 and Phase 2 using the following approach.

For nation $j \in S$, let $M_j$ denote its military power and $E_j$ its economic power. If the game ends in phase 2 in state $(x_B, S_B, x_R, S_R)$, then

$$V_B(s) = \frac{\left(x_B + \sum_{j \epsilon S_B} M_j\right)^2}{\left(x_B + \sum_{j \epsilon S_B} M_j\right)^2 + \left(x_R + \sum_{j \epsilon S_R} M_j\right)^2} \times K - \sum_{j \in R} E_{j,} \tag{3.1}$$

$$V_R(s) = \frac{\left(x_R + \sum_{j \epsilon S_R} M_j\right)^2}{\left(x_B + \sum_{j \epsilon S_B} M_j\right)^2 + \left(x_R + \sum_{j \epsilon S_R} M_j\right)^2} \times K - \sum_{j \in B} E_j\,, \tag{3.2}$$

where $K$ is a large reward, which can be interpreted as the reward for defeating the other player in the Phase 2 conflict. We objectively define the value of $K$ by the value of military objectives, such as forcing the adversary to recognize territorial claims, or destroying military assets that allow the adversary to enforce territorial claims. One possibility is to set $K = \sum_{j \in S} E_{j.}$ The probability of winning the war is proportional to the square of the force size in each alliance (Lanchester's square law).

If the game ends in Phase 0 in state $(x_B, S_B, x_R, S_R)$, then

$$V_B(s) = V_B(0) - \beta_B \sum_{j \in R} E_j\,, \tag{3.3}$$

$$V_R(s) = V_R(0) - \beta_R \sum_{j\in B} E_j , \tag{3.4}$$

where $V_B(0)$, $V_R(0)$ are status quo payoffs, and $\beta_B, \beta_R \in [0, 1]$ represents goodwill lost between the player and nations that join the alliance of the opposing player. One possibility is to set

$$V_B(0) = \alpha_B \sum_{j\in S} E_j , \tag{3.5}$$

$$V_R(0) = \alpha_R \sum_{j\in S} E_j , \tag{3.6}$$

where $\alpha_B$ and $\alpha_R$ are coefficients for each player.

Finally, if one player decides to enter Phase 0, while the other does not, then the player that decided to enter Phase 0 loses influence in the region, therefore incurring a penalty $C_i$ for $i = B, R$. Let

$$C_B = \gamma_B \sum_{j\in S} E_j , \tag{3.7}$$

$$C_R = \gamma_R \sum_{j\in S} E_j , \tag{3.8}$$

where $\gamma_B$ and $\gamma_R$ are coefficients. The other player earns influence in the region, gaining $C_i$, for $i = B, R$. If both players decide to enter Phase 0 in the same round then this penalty or reward does not apply.

## C. SOLVING A MATRIX GAME IN EACH ROUND

At the beginning of a round, write the state as $s = (x_B, S_B, x_R, S_R)$. Each player has several pure strategies:

- $P0$: Enter Phase 0.
- $P2$: Enter Phase 2.
- $AF$: Increase force size by 1 unit.
- $Dj$: Make a diplomatic move on nation $j$, for $j \in S \setminus (S_B \cup S_R)$

Each player has at least two pure strategies $P0$ and $P2$. If the player has not maxed out its force presence, then the player can choose $AF$ to increase its force presence. In addition, each player can make a diplomatic move on a neutral nation. In each state, we need to solve a two-person nonzero-sum game. The number of pure strategies for each player ranges between 2 and $2 + 1 + n = n + 3$.

In a two-person nonzero-sum matrix game, there are many solution concepts, such as Nash equilibrium, Nash arbitration solution, and prudential strategy. We adopt the prudential strategy, which allows each player to obtain his security level by the optimal strategy in his own game as if it were a zero-sum game. In other words, each player maximizes what he can guarantee for himself. The security level for player $i$ is therefore $V_i(s)$, for $i = B, R$.

## D. PYTHON IMPLEMENTATION

We use Python to implement the Markov game, and use Pyomo to implement the linear program needed to solve the matrix game in each round.

## E. VALUE OF DETERRENCE

The Markov game continues, remaining in Phase 1, until a player chooses to transition to Phase 0 or Phase 2. We consider Blue's standpoint, and define deterrence as the event that Red eventually chooses action $P0$ to end the Markov game. After we compute the optimal mixed strategy of both players in all states, we can compute the probability that Red will eventually choose action $P0$ before Blue enters Phase 0 or Phase 2, at some point in each state, denoted by $P(s)$, for $s \in S$.

Suppose the current state is $s$, and we want to assess the deterrence value if Blue adds one CSG to the region. Let $s'$ denote the new state after Blue adds one CSG. The

difference $P(s')— P(s)$ can be interpreted as the deterrence value of adding one CSG, since it is the difference in probability that Red will eventually choose to enter Phase 0 at some point in the future.

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# III. A CASE STUDY

This chapter presents a case study, which applies the Markov game model in Chapter II to a specific scenario in the South China Sea. The model parameters are estimated from open-source data.

## A. SCENARIO IN THE SOUTH CHINA SEA

Imagine in 2020, tension in the South China Sea rises due to Chinese expansionism and territorial claims. China continues its aggressive terraforming campaigns and is militarizing islands in the South China Sea. The People's Liberation Army seeks to increase its strategic position and posture within the maritime region. There have been recent altercations with Vietnam over EEZ rights around the Spratly Islands. Several nations in the region condemn the recent escalation and Chinese expansive actions, but make pleas for a peaceful resolution and a reduction in regional tensions. China asserts their rightful claim to, what they state are, historical Chinese sovereign territories and fishing zones. Further, China pledges to protect their land and waterways, with military force if necessary. In response to Chinese aggression, Vietnam appeals to the United States for assistance. In this case study, the United States is assigned as the Blue player and China is assigned as the Red player. A group of six nations within the South China Sea region are chosen to fill the role of the nations in the game. These six nations are the Philippines, Vietnam, Taiwan, Singapore, Indonesia, and Malaysia.

## B. MODEL INPUT

Several assumptions were made for the model's input parameters. These assumptions, while recognized as imperfect, are considered reasonable, allowing demonstration of the Markov game in a particular scenario. The costs for player action and reward payoff is measured in millions of dollars ($M). Each round covers an approximate time frame of three days. The model parameters are stored in an Excel spreadsheet and are easily adapted. Pandas is used to create the data frames from the data in our spreadsheet for use in the Python model.

The game players are the United States and China. Each player has specific parameters defining the size of its available military force, the cost to deploy those forces, and the cost to maintain the forces in the South China Sea. The U.S. player requires five parameters to define its military strength, which are summarized in Table 1. The number of deployable CSGs varies from zero up to the maximum force size of three CSGs. We define each CSG as a unit of force. The cost to increase force varies depending on the current force level. For example, the cost to deploy the first CSG is $5M, the second CSG is $10M, and the third CSG is $20M. The cost to maintain each unit of force, is assumed at $4M per day, for a total cost of $12M per round. The cost to increase the number of CSGs in the region is a one-time cost, realized at the time force level is adjusted. China's military strength is defined similarly, but using only four parameters, since we set China's maximum force level at two. We consider each unit of China's military force comparable to the military striking power of one U.S. CSG. The cost to increase Chinese forces is $3M for the first force level and $4M for the second force level. The recurring cost for China to maintain each unit of force is $2M, over the three-day time frame. We assign different costs to maintain force, between the U.S. and China, as a result of each respective player's distance from the operating area. We assume that greater distance to the operating area equates to larger deployment and maintenance costs for the respective player. The U.S. maintenance cost is assumed at a six to one ratio with respect to China's equivalent cost.

Table 1. Player Military Strength Parameters

| Military strength parameters | | | | | |
|---|---|---|---|---|---|
| Player | Max force | Maintain force ($M) | Increase force (0 to 1) ($M) | Increase force (1 to 2) ($M) | Increase force (2 to 3) ($M) |
| U.S. | 3 | 12 | 5 | 10 | 20 |
| China | 2 | 2 | 3 | 4 | NA |

The military strength of each player is derived from the column parameters. The number of deployable forces range from zero up to the respective maximum force size for each player. The cost to maintain force is paid per unit of force in the operating area. The cost to increase forces is a one-time cost whose amount depends upon the specific force level.

In lieu of subject matter expert's assessment, we use equations (3.1) through (3.8) to calculate payoffs in Phase 0 and Phase 2, and determine the final payoff for each player. Table 2 summarizes the three coefficients, $\alpha, \beta,$ and $\gamma$, needed to calculate these payoffs.

Table 2. Player Payoff Coefficients

| Payoff coefficients | | |
|---|---|---|
| Coefficient | U.S. | China |
| Alpha | 0.4 | 0.5 |
| Beta | 0.2 | 0.2 |
| Gamma | 0.05 | 0.1 |

Coefficient are used in the calculation of payoffs for each phase of conflict. Alpha is used for calculating the status quo payoff. Beta applies to the Phase 0 payoff. Gamma is used in calculating the penalty and/or reward for transitioning to Phase 0.

Each regional nation has a military strength and an economic value. We base each nation's military strength on a rating derived from Global Firepower (GF). Global Firepower (n.d.) provides analytical data for over 100 of the world's strongest militaries and is part of the Military Factory network. GF ranks a nation's military strength according to a "Power Index" which considers many factors in determining its final rankings. Some factors they consider include size and number of conventional forces, population, natural and available resources, and diversity of military hardware. We convert this index to a scale between 0 and 1, where a higher value indicates a stronger military force. In the model, the military strength parameter represents each nation's military striking power in relation to a single unit of force of either the U.S. or China. For example, a nation with a military strength value of 0.5, contributes military power equivalent to one-half of a U.S. CSG or Chinese unit of force. Economic strength is derived from the nation's GDP and is measured in millions of dollars. This data was collected from the International Monetary Fund's (n.d.) World Economic Outlook Database. Table 3 summarizes the military and economic strength parameters for each nation.

Table 3. Regional Nation Military and Economic Strength Parameters

| Nation parameters | | |
|---|---|---|
| Nation | Military Strength | Economic Strength ($M) |
| Philippines | 0.1456 | 329,716 |
| Vietnam | 0.4378 | 215,829 |
| Taiwan | 0.4202 | 566,757 |
| Singapore | 0.0961 | 291,860 |
| Malaysia | 0.2279 | 309,860 |
| Indonesia | 0.4627 | 1,020,525 |

Military strength is a measure of a nation's military power compared to one unit of force of either the U.S. or China. Economic strength is an approximation which is based on the GDP outlook for each nation.

The model includes relationship parameters which define the interaction between the two players and the six regional nations. The diplomatic tie measures the relationship of each nation to each player. We assume a value based on a subjective assessment utilizing analysis from *The Military Balance* (International Institute for Strategic Studies 2017) and the scenario used in the wargame case study (Akin et al. 2017). The International Institute for Strategic Studies, a research institute based in London, publishes *The Military Balance* annually, which provides statistics on nations' military forces and defense expenditures. The cost for a player to seek an alliance with a nation, defined as the diplomatic move cost, is calculated by taking the ratio of a nation's GDP to its diplomatic tie with each respective player. The cost is scaled to be represented in millions of dollars. Table 4 summarizes the diplomatic ties and diplomatic costs.

Table 4. Relationship Parameters Between Players and Nations

| Interaction between players and nations | | | | |
|---|---|---|---|---|
| | U.S. | | China | |
| Nation | Diplomatic tie | Diplomatic cost ($M) | Diplomatic tie | Diplomatic cost ($M) |
| Philippines | 0.50 | 6.59 | 0.50 | 6.59 |
| Vietnam | 0.70 | 3.08 | 0.30 | 7.19 |
| Taiwan | 0.80 | 7.08 | 0.50 | 11.34 |
| Singapore | 0.70 | 4.17 | 0.50 | 5.84 |
| Malaysia | 0.50 | 6.20 | 0.60 | 5.16 |
| Indonesia | 0.60 | 17.01 | 0.50 | 20.41 |

The diplomatic tie defines the relationship between the nation and respective player. In addition, the diplomatic tie denotes the probability that a nation will join the alliance of a player. The diplomatic cost, measured in millions of dollars, is the ratio of the nation's GDP to its diplomatic tie with each respective player. It represents a player's cost to pursue an alliance with a specific nation.

The particular nations we select for the two, three, and six nation sets are chosen to draw parallels with the wargame case study and provide a basis for comparison. We recognize that the specific nations in each set will affect the game's numeric values due to differences in respective military and economic strengths.

## C. MODEL OUTPUT

The model provides several output values which capture the number of forces in the current state, the probability of deterrence, the expected payoff for each player, the pure strategy sets, and the optimal mixed strategies. The following provides a brief summary of each output value:

- Blue force: The number of Blue forces in the operating area
- Red force: The number of Red forces in the operating area
- Deterrence probability: The probability that the Red player will choose to enter Phase 0
- Expected payoff: Each player's expected payoff in the current state ($M)
- Strategy set: The set of pure strategies for the player
- Mixed strategy: The optimal mixed strategy for the player

We provide the following two nation example to demonstrate model output. In this example, Blue (United States) and Red (China) have no alliances; in other words, all nations remain neutral. There are two nations in this example, nation 0 (Philippines) and nation 1 (Vietnam). Table 5 provides example output for the Blue player, while Table 6 provides output for the Red player.

Table 5. Example Blue Player Output

Example model output for Blue player

| Blue force | Red force | Deterrence probability | Expected payoff ($M) | Strategy set | Mixed strategy |
|---|---|---|---|---|---|
| 0 | 0 | 0.98 | 1802 | {P0, P2, AF, 0, 1} | [0, 0, 0.71, 0.29, 0] |
| 0 | 1 | 0 | 1584 | {P0, P2, AF, 0, 1} | [0.82, 0, 0, 0.18, 0] |
| 0 | 2 | 0 | 1580 | {P0, P2, AF, 0, 1} | [1, 0, 0, 0, 0] |

Columns one and two indicate each player's respective force level in the operating area. Column three is the probability of deterrence. The fourth column gives the expected payoff for the Blue player. The fifth column lists Blue's pure strategies available, while column six lists the optimal mixed strategy for the given pure strategy set.

We interpret the data by row and begin by examining the first row in Table 5. Columns one and two indicate that there are zero forces in the operating area. Column three gives a probability of deterrence, or the probability that neither player will choose to escalate, of 0.98. Column four shows Blue's expected payoff at \$1.802B. The next column lists Blue's available pure strategy set. In this case, Blue has the option to enter Phase 0 ($P0$), enter Phase 2 ($P2$), increase force size ($AF$), seek an alliance with nation 0 (Philippines), or seek an alliance with nation 1 (Vietnam). The final column lists the optimal mixed strategy which Blue should play his pure strategy set. Blue should increase force level with a probability 0.71 and should seek an alliance with the Philippines with a probability 0.29. The second and third row can be interpreted in a similar manner.

Table 6. Example Red Player Output

Example model output for Red player

| Blue force | Red force | Deterrence probability | Expected payoff ($M) | Strategy set | Mixed strategy |
|---|---|---|---|---|---|
| 0 | 0 | 0.98 | 1870 | {P0, P2, AF, 0, 1} | [0.85, 0, 0.15, 0, 0] |
| 0 | 1 | 0 | 2728 | {P0, P2, AF, 0, 1} | [0, 1, 0, 0, 0] |
| 0 | 2 | 0 | 1580 | {P0, P2, 0, 1} | [0, 1, 0, 0] |

Columns one and two indicate each player's respective force level in the operating area. Column three is the probability of deterrence. The fourth column gives the expected payoff for the Red player. The fifth column lists Red's pure strategies available, while column six lists the optimal mixed strategy for the given pure strategy set.

Next, we examine the same example from Red's perspective, given in the first row of Table 6. The output in the first three columns is unchanged; however, Red has a different expected payoff of $1.870B. Since this state represents the beginning of our Markov game, Red has the same pure strategy set as Blue, although this is not always the case. If we examine row three's pure strategy set, we note that there are only four pure strategies available, since Red has maximized his force level at 2 units of force. Thus, the strategy to increase force level has been removed from his set. Returning to row one, we notice that Red's optimal mixed strategies are different from the Blue player. Red should enter Phase 0 with a probability of 0.85 and should increase force level with a probability of 0.15.

Finally, let us review the second row of both Blue and Red in Table 5 and Table 6. The current state remains at no alliances, with zero Blue presence, seen in column one and column two of both tables. However, Red's force level has increased to one. Reviewing the pure strategy sets and optimal mixed strategies, we see that Blue should enter Phase 0 with probability of 0.82 and should seek an alliance with the Philippines with probability of 0.18. In contrast, Red should enter Phase 2 with a probability of 1. Therefore, the probability of deterrence, as defined in the model, is equal to 0, seen in column three of both tables. This can be interpreted as Red seizing the initiative while having a force advantage, escalating to Phase 2 and maximizing his expected payoff (the value of the game).

## D. RESULTS AND ANALYSIS

In order to gain insights into the deterrence value of CSGs, we conduct three variations of this case study by varying the number of regional nations in each game. The first variation of our case study, a two nation Markov game, considers two of the six nations, the Philippines and Vietnam. Our second variation, a three nation Markov game, adds Taiwan into the nation set. In the final variation, a six nation Markov game, we add Singapore, Indonesia, and Malaysia.

### (1) The Case With Two Regional Nations

The first case study examines a two-nation set which consists of the Philippines and Vietnam. In this case, $n = 2$, so there are $3^2$, or 9 sets of diplomatic alliance combinations. Table 7 lists all possible alliance combinations for the two-nation set. Given a maximum Blue force size of 3 and a maximum Red force size of 2, we can calculate the size of our state space. The total number of states is $4 \times 3 \times 9 = 108$, where 4, 3, and 9 are the range of Blue forces, the range of Red forces, and the number of diplomatic alliance combinations, respectively.

Table 7. Two Nation Diplomatic Alliance Combinations

| Combinations of two nation diplomatic alliances | | |
|---|---|---|
| Neutral | U.S. | China |
| Philippines, Vietnam | | |
| Vietnam | Philippines | |
| Vietnam | | Philippines |
| Philippines | Vietnam | |
| | Philippines, Vietnam | |
| | Vietnam | Philippines |
| Philippines | | Vietnam |
| | Philippines | Vietnam |
| | | Philippines, Vietnam |

The number of possible diplomatic alliances is given by $3^n$, where $n$ is the number of nations. In this case, $n = 2$, so there are $3^2$, or 9 sets of diplomatic alliance combinations.

Table 8 provides Phase 0 payoffs for each player in a two-nation set. Each player has an expected payoff for each diplomatic alliance combination. We observe a higher payoff when all nations remain neutral or a player has a diplomatic advantage over the other player. The Phase 0 expected payoffs are calculated using equations (3.3) and (3.4).

Table 8. Phase 0 Payoff

Phase 0 payoff for the U.S. and China in a two nation set

| Diplomatic alliances | | | Expected payoff ($M) | |
|---|---|---|---|---|
| Neutral | U.S. | China | U.S. | China |
| Philippines, Vietnam | | | 2182 | 2728 |
| Vietnam | Philippines | | 2182 | 2068 |
| Vietnam | | Philippines | 1523 | 2728 |
| Philippines | Vietnam | | 2182 | 2296 |
| | Philippines, Vietnam | | 2182 | 1637 |
| | Vietnam | Philippines | 1523 | 2296 |
| Philippines | | Vietnam | 1751 | 2728 |
| | Philippines | Vietnam | 1751 | 2068 |
| | | Philippines, Vietnam | 1091 | 2728 |

This table lists all possible diplomatic alliance combinations for a two-nation set. The last two columns list the expected Phase 0 payoff for the U.S. and China.

Table 9 provides the Phase 2 payoffs for the players when the U.S. has no nation in its alliance and China is allied with the Philippines. The values are monotonic for each player. For example, the expected payoff for the U.S. increases as more CSGs are deployed to the operating area. As Chinese forces increase, we see that the U.S. expected payoff either stays the same or decreases. Phase 2 expected payoff is calculated using equations (3.1) and (3.2).

Table 9. Phase 2 Payoff

Phase 2 payoff when U.S. has no alliance and China is allied with Philippines

| | Expected payoff (U.S., China) ($M) | | |
|---|---|---|---|
| | China | | |
| U.S. | 0 | 1 | 2 |
| 0 | (-3297, 5456) | (-3297, 5456) | (-3297, 5456) |
| 1 | (2045, 113) | (-938, 3096) | (-2324, 4482) |
| 2 | (2130, 29) | (811, 1348) | (-761, 2919) |
| 3 | (2146, 13) | (1464, 694) | (312, 1846) |

This table provides the expected payoff in Phase 2 for the U.S. and China. We choose the diplomatic alliance combination when the U.S. has no nation in its alliance and China is allied with the Philippines. The table presents all possible combinations of force levels in the operating area. The values in the parentheses are the expected payoff for the players in millions of dollars. (U.S., China)

The main metric we use in our analysis is the probability of deterrence, defined as the probability that China will eventually choose to enter Phase 0 before Blue enters Phase 0 or Phase 2. We group the probabilities according to each diplomatic alliance combination in the nation set. We will refer to each grouping as an instance. Each instance is further delineated by the combination of Blue and Red force levels in the operating environment.

We also make a distinction based upon whether or not one player has a diplomatic advantage over the other. If the U.S. and China have no alliances, or they each have one nation in their alliance, then we consider neither nation to have the diplomatic advantage. However, if the U.S. has two nations in its alliance and China has zero, then the U.S. has the diplomatic advantage. The same logic applies to China. The diplomatic advantage is purely a numeric advantage, i.e., more nations in an alliance. It is conceivable that the U.S. could have one nation in its alliance, while China could have two nations, yet possess an advantage based on the strength of the particular nation in its alliance. For example, if Indonesia is allied with the U.S., while the Philippines and Singapore are allied with China, the U.S. technically has a diplomatic advantage. Referencing Table 3, we note that Indonesia is stronger, in terms of both military and economic strength, than the combination of the Philippines and Singapore. We do not make that distinction in the

following cases, and say that China retains the diplomatic advantage since it has more nations in its alliance.

Table 10 provides our results when there is no clear diplomatic advantage amongst the players. We begin with the instance of no diplomatic alliances, and observe that our data is monotonic. When there are no forces in the region, the probability of deterrence is 0.98. If the U.S. maintains zero presence while China increases its force level, we observe that the deterrence probability drops to zero. If the U.S. maintains parity with the level of Chinese forces, then the probability of deterrence is 1. In fact, any level of U.S. presence deters the enemy, except the case when Chinese force levels are greater than U.S. force levels. We infer that U.S. CSG presence provides an effective means of deterrence.

The next two instances are similar, the U.S. and China each have one nation in their respective alliance. The analysis is clear, the U.S. deters with a probability of 1, regardless of force presence. In other words, presence does not affect the likelihood of combat. We can infer that the diplomatic state drives the outcome in these instances.

Table 10. Two Nation Game With No Diplomatic Advantage

**Probability of deterrence based on force level, with no diplomatic advantage**

| | China | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | No Alliances | | | U.S. has Vietnam China has Philippines | | | U.S. has Philippines China has Vietnam | | |
| U.S. | 0 | 1 | 2 | 0 | 1 | 2 | 0 | 1 | 2 |
| 0 | 0.98 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

The probability of deterrence is displayed based on U.S. and Chinese force levels. Each row indicates how many U.S. carrier strike groups are in the region, from zero up to three. The columns display three different alliance combinations. The first group shows the situation where all nations are neutral. The second group is the alliance combination where Vietnam is allied with the U.S. and the Philippines is allied with China. Group three is the opposite of group two. Each alliance combination displays China's force level from zero up to two.

Table 11 demonstrates results when the U.S. has a clear diplomatic advantage over China. In all three instances, China has no nation in its alliance and the probability of deterrence is 1, regardless of force levels. We infer that U.S. presence, coupled with diplomatic advantage, provides an effective deterrence.

Table 11. Two Nation Game When the U.S. Has a Diplomatic Advantage

**Probability of deterrence based on force level, when China has no alliance**

| | China | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | U.S. has Philippines | | | U.S. has Vietnam | | | U.S. has Philippines, Vietnam | | |
| U.S. | 0 | 1 | 2 | 0 | 1 | 2 | 0 | 1 | 2 |
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

The probability of deterrence is displayed based on U.S. and Chinese force levels. Each row indicates how many U.S. carrier strike groups are in the region, from zero up to three. The columns display three different alliance combinations. In all combinations, the U.S. has the diplomatic advantage. Each alliance combination displays China's force level from zero up to two.

The results are more interesting when China has the diplomatic advantage, seen in Table 12. In all three instances, the U.S. has no nation in its alliance. In the first instance, when China is allied with the Philippines, we observe that only U.S. force advantage guarantees deterrence. In the second instance, China is allied with Vietnam, which is the stronger of the two nations. The results show that U.S. force advantage alone does not guarantee deterrence. When China introduces any forces into the area, U.S. presence does not deter in most force level combinations. Only a three to one force advantage for the U.S. offers any means of curbing Chinese aggression. Our final instance demonstrates the effect of a large diplomatic advantage. Again, we note that U.S. presence alone does not deter. Reviewing all three instances we see that by increasing CSG presence we will never see a decrease in the deterrence probability. In some cases, we either see no change or a marginal increase. In others, the addition of a CSG dramatically increases the probability of deterrence.

Table 12. Two Nation Game When China Has a Diplomatic Advantage

Probability of deterrence based on force level, when U.S. has no alliance

| | China | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | China has Philippines | | | China has Vietnam | | | China has Philippines, Vietnam | | |
| U.S. | 0 | 1 | 2 | 0 | 1 | 2 | 0 | 1 | 2 |
| 0 | 0.45 | 0 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1 | 0.27 | 0 | 0.7 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 |
| 3 | 1 | 1 | 1 | 1 | 0.71 | 0 | 1 | 0 | 0 |

The probability of deterrence is displayed based on U.S. and Chinese force levels. Each row indicates how many U.S. carrier strike groups are in the region, from zero up to three. The columns display three different alliance combinations. In all combinations, China has the diplomatic advantage. Each alliance combination displays China's force level from zero up to two.

Observing the results from our two-nation case study, we see that adding one CSG either increases the deterrence probability, or maintains the same deterrence probability. Deterrence probability also increases if the U.S. has a force advantage. When comparing across Tables 10–12, we see that the deterrence probability also increases if U.S. adds a nation into its alliance, and decreases if China adds a nation into its alliance.

(2) The Case With Three Regional Nations

Our second case study examines a Markov game with three regional nations. The regional nation set for this Markov game consists of the Philippines, Vietnam, and Taiwan. In this game, there are 27 sets of diplomatic alliance combinations and 324 total states. We will review 9 of the 27 alliance combinations that are most interesting.

We begin by reviewing the instance where neither player has a clear diplomatic advantage. Table 13 displays the results. In the first instance, all nations are neutral. U.S. force parity provides effective deterrence. In the next instance, we examine the situation where the U.S. is allied with Taiwan and China is allied with Vietnam. We note from Table 3, that although Taiwan and Vietnam have a similar military strength value, Taiwan's economic strength is approximately twice that of Vietnam. Presence and a strong alliance allows the U.S. to deter with certainty. We infer that adding a strong

nation into the U.S. alliance helps deter China's aggression. In the last instance, we examine the case when the U.S. is allied with Vietnam and Taiwan is allied with China. U.S. parity or force advantage guarantee effective deterrence.

Table 13. Three Nation Game With No Diplomatic Advantage

Probability of deterrence based on force level, with no diplomatic advantage

| | China | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | No alliances | | | U.S. has Taiwan China has Vietnam | | | U.S. has Vietnam China has Taiwan | | |
| U.S. | 0 | 1 | 2 | 0 | 1 | 2 | 0 | 1 | 2 |
| 0 | 1 | 0 | 0 | 1 | 1 | 0.69 | 1 | 0.73 | 0 |
| 1 | 1 | 1 | 0.66 | 1 | 1 | 1 | 1 | 1 | 0.72 |
| 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

We now review the results when China possesses a clear diplomatic advantage over the U.S. player. The results are available in Table 14. The first instance is comparable to the same diplomatic state in the two-nation game, seen in Table 12. The U.S. has no nation in its alliance, while the Philippines and Vietnam are allied with China. Force presence affects the probability of deterrence. However, only overwhelming force levels for the U.S. is effective. As the U.S. increases its force level, we see an increase in probability, regardless of Chinese force levels. This is not the same outcome as seen in Table 12. The addition of a third nation in the set affects the outcome.

In the next instance, we see that the alliance for China is unchanged, but the U.S. has now added Taiwan into its alliance. Referring again to Table 3, we see that Taiwan's economic strength is greater than the Philippines and Vietnam combined. As a result, we see that force presence and diplomatic strength enable the U.S. to deter in all force level combinations.

The last instance displays the results when the U.S. has no nations in its alliance and Taiwan is allied with China. Only U.S. force advantage guarantees deterrence.

Table 14. Three Nation Game When China Has the Diplomatic Advantage

Probability of deterrence based on force level, when China has more alliances

| | China | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | China has Philippines, Vietnam | | | U.S. has Taiwan<br>China has Philippines, Vietnam | | | China has Taiwan | | |
| U.S. | 0 | 1 | 2 | 0 | 1 | 2 | 0 | 1 | 2 |
| 0 | 0.08 | 0 | 0 | 1 | 1 | 1 | 0.56 | 0 | 0 |
| 1 | 0.80 | 0.06 | 0 | 1 | 1 | 1 | 1 | 0.52 | 0 |
| 2 | 0.96 | 0.39 | 0.07 | 1 | 1 | 1 | 1 | 1 | 0 |
| 3 | 1 | 0.93 | 0.19 | 1 | 1 | 1 | 1 | 1 | 1 |

The final results in the three-nation set, seen in Table 15, also examine the effect of presence when China maintains a diplomatic advantage. We first examine the instance when the U.S. has no nations in its alliance and China is allied with the Philippines and Taiwan. Clearly, the U.S. must have a three to one force advantage to provide any measure of deterrence. With anything below this force advantage, the probability of deterrence is essentially zero. We infer that an adversary's strong diplomatic alliance can offset U.S. numerical advantage. The U.S. needs to deploy CSGs quickly, before China assembles its forces in the area, and must maintain a substantial force advantage.

In the next instance, China's alliance remains the same, while the U.S. adds Vietnam into its alliance. Adding a strong nation into its alliance allows the U.S. to deter with certainty. We again observe that the combination of presence and diplomatic alliance provide an effective deterrence against Chinese presence.

Finally, we look at the instance where all nations in our regional set are in alliance with China. The probability of deterrence is zero once China introduces any force into the operating area. Clearly, the strength of diplomatic alliance is greater than the strength brought to the region by U.S. presence.

Table 15. Three Nation Game When China Maintains a Diplomatic Advantage

| Probability of deterrence based on force level, when China has more alliances | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | China | | | | | | | | |
| | China has Philippines, Taiwan | | | U.S. has Vietnam China has Philippines, Taiwan | | | China has Philippines, Vietnam, Taiwan | | |
| U.S. | 0 | 1 | 2 | 0 | 1 | 2 | 0 | 1 | 2 |
| 0 | 0.01 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 1 | 0.04 | 0.01 | 0 | 1 | 1 | 1 | 0 | 0 | 0 |
| 2 | 0.93 | 0.02 | 0 | 1 | 1 | 1 | 0 | 0 | 0 |
| 3 | 1 | 0.83 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |

(3) The Case With Six Regional Nations

Our final case study examines a Markov game with six regional nations. The regional nation set for this game consists of the Philippines, Vietnam, Taiwan, Singapore, Malaysia, and Indonesia. There exist 729 sets of diplomatic alliance combinations and 8,748 total states. We will review the three most interesting instances when China has the diplomatic advantage. Table 16 provides our results.

In the first instance, China is allied with four of the nations while the U.S. is only allied with one nation. The effect of China's diplomatic advantage is clearly seen. With no Chinese force presence, the U.S. only deters when it has two or more CSGs in the region. However, as Chinese forces are introduced into the region, the probability of deterrence rapidly decreases towards zero.

In the second instance, China maintains a diplomatic advantage. Taiwan and Indonesia provide China with strong military and economic power. Only force advantage provides the U.S. with an effective means of deterrence.

The final instance examines the case when the U.S. is allied with Taiwan and Indonesia, while China is allied with the remaining nations. China has the numerical advantage in terms of nations in its alliance. However, Taiwan and Indonesia are the two strongest nations in terms of economic power and in the top three nations in terms of military strength. Clearly, the strength of the U.S. alliance, in conjunction with CSG presence, deters with certainty.

Table 16. Six Nation Game When China Has the Diplomatic Advantage

Probability of deterrence based on force level, when China has more alliances

| | China | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | U.S. has Philippines China has Vietnam, Singapore, Malaysia, Indonesia | | | U.S. has Philippines, Vietnam China has Taiwan, Singapore, Indonesia | | | U.S. has Taiwan, Indonesia China has Philippines, Vietnam, Singapore, Malaysia | | |
| U.S. | 0 | 1 | 2 | 0 | 1 | 2 | 0 | 1 | 2 |
| 0 | 0 | 0 | 0 | 0.65 | 0 | 0 | 1 | 1 | 1 |
| 1 | 0.03 | 0 | 0 | 0.95 | 0 | 0 | 1 | 1 | 1 |
| 2 | 0.86 | 0.03 | 0.02 | 0.97 | 0.93 | 0 | 1 | 1 | 1 |
| 3 | 1 | 0.77 | 0.02 | 0.98 | 0.96 | 0.91 | 1 | 1 | 1 |

(4) Comparison Between Two, Three, and Six Nation Sets

We compare the two, three, and six nation sets, across similar alliance combinations. Our first comparison is the case when there are no diplomatic alliances (i.e., all nations remain neutral). The second comparison is the situation when the U.S. has no nation in its alliance and China is allied with the Philippines and Vietnam.

Table 17 provides the comparison when there are no diplomatic alliances for either player. The results from the two-nation set demonstrate that U.S. parity with Chinese forces deters in all force level combinations. Reviewing the three-nation set, we see that U.S. force parity with China continues to guarantee deterrence. Further, we see that the addition of another nation into the game increases the U.S. probability of deterrence. The six-nation set presents a slightly different result. We observe that U.S. parity does not guarantee absolute deterrence, but has a lower probability of deterrence at some force levels. With six nations in our set, it is possible that China can get lucky and add several nations into its alliance. If China gets 5 nations to join its alliance and the U.S. only gets 1 nation, then China may not choose to transition to Phase 0, even if the U.S. has a force advantage. With only two nations in the set, the best China can hope for is to gain alliances with those two nations, which does not guarantee China a decisive diplomatic advantage. To draw an analogy from a basketball game, more nations in the set is analogous to more time remaining in the game. A team (China) that trails by 10 points in the first quarter with three quarters to play (6 nations to grab) has a better

chance to overcome the deficit to win the game rather than a team that trails by 10 points with only 3 minutes to play (2 nations to grab).

Table 17. Two, Three, and Six Nation Comparison, No Alliances

Probability of deterrence based on force level
U.S. and China have no alliances

| | China | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Two nation set | | | Three nation set | | | Six nation set | | |
| U.S. | 0 | 1 | 2 | 0 | 1 | 2 | 0 | 1 | 2 |
| 0 | 0.97 | 0 | 0 | 1 | 0 | 0 | 0.84 | 0 | 0 |
| 1 | 1 | 1 | 0 | 1 | 1 | 0.66 | 1 | 0.90 | 0 |
| 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

This table provides the probability of deterrence across a similar state in the two, three, and six nation sets. For both players, the U.S. and China, there are no nations in their respective diplomatic alliance.

Finally, we examine the case when the U.S. has no nations in its alliance and China is allied with the Philippines and Vietnam. Our results are seen in Table 18. We first review the two-nation results. Clearly, U.S. force level provides little, to no, deterrence value, especially once China introduces forces into operating area. In the next instance, we observe the effect of adding a third nation into the set. U.S. presence has a higher probability of deterring Chinese aggression, but only with a substantial force advantage. Finally, with six nations in the set, U.S. force advantage provides deterrence with certainty.

Table 18. Two, Three, and Six Nation Comparison, Similar Alliances

Probability of deterrence based on force level
U.S. has no alliance, China allied with the Phillipines and Vietnam

| | China | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Two nation set | | | Three nation set | | | Six nation set | | |
| U.S. | 0 | 1 | 2 | 0 | 1 | 2 | 0 | 1 | 2 |
| 0 | 0 | 0 | 0 | 0.08 | 0 | 0 | 0.34 | 0 | 0 |
| 1 | 0 | 0 | 0 | 0.80 | 0.06 | 0 | 1 | 0.01 | 0 |
| 2 | 1 | 0 | 0 | 1 | 0.39 | 0.07 | 1 | 1 | 0.54 |
| 3 | 1 | 0 | 0 | 1 | 0.93 | 0.19 | 1 | 1 | 1 |

This table provides the probability of deterrence across a similar state in the two, three, and six nation sets. The U.S. has no nations in its alliance while China is allied with the Philippines and Vietnam.

## E. INFERENCES

The results from our two, three, and six nation case studies allow us to make several inferences about how CSG presence and diplomatic alliances affect the probability that a conflict will occur.

Carrier presence, coupled with diplomatic advantage, provides the most effective means of deterrence. In some cases, force presence alone was an effective deterrent to conflict. In other cases, only substantial and overwhelming force advantage deterred enemy aggression. Still, in other cases, presence alone was not effective and required strong diplomatic alliance to prevent conflict. During Phase 0, the shaping phase, the U.S. should build strong diplomatic ties in the region. A player's diplomatic tie directly affects whether or not a nation will join its alliance. The stronger the diplomatic tie with a player, the more likely that nation is to join that player's diplomatic alliance. During Phase 1, the deterrence phase, the U.S. should act quickly to build presence and diplomatic advantage. Our analysis indicates that when this is the case, the U.S. is able to deter with certainty in the majority of instances. The game results demonstrate that, even with force and diplomatic advantage, there are some instances when the U.S. should choose to enter Phase 2 and seize the initiative.

We also observe that the number of nations in the region, and their military and economic strengths, effect the probability of deterrence. We note our model's sensitivity to the regional nation's input parameters. Stronger nations, such as Indonesia and Taiwan, are more effective at enabling U.S. deterrence and prove to be desirable partners in an alliance. We observe that as the number of nations in the set increases, our probabilities vary due to the change in economic and military incentives available to the U.S. and China.

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# IV. CONCLUSION

In this thesis, we develop a game-theoretic model, within the construct of a Markov game, to quantify how the presence of a CSG can deter the aggressive military action of enemy forces. We focus on a geographical region where tension among nations threatens regional stability. Two regional nations, a global power and a regional power, represent the main players in our game. All other nations in the region are modeled as random events. Each player deploys forces to the operating area and seek alliances with the other nations to strengthen their position. We approach the problem within the DIME construct, and quantify the strength and relations among the nations in the region. The game is conducted in Phase 1 and ends when a player chooses to transition to Phase 0 or Phase 2. A case study focuses on the South China Sea, where the United States represents the global power and China represents the regional power. The regional nations consist of the Philippines, Vietnam, Taiwan, Singapore, Indonesia, and Malaysia. We conduct three variations of the case study, examining the effect of a two, three, and six regional nation sets.

## A. LESSONS LEARNED

Models represent abstraction of reality, and prediction is not always the aim of modeling (Epstein 2008). Even with open-source data that may not reflect precisely a real-world military conflict, the analysis of model output provides decision makers with insight into such situations. Here, we summarize the most important lessons learned from our Markov game model and the case study.

From our case study results, we infer that carrier presence, coupled with a strong diplomatic alliance, provides the most effective means of deterring enemy aggression. CSG presence alone, is only effective in some cases. In other cases, the presence of the CSG has no deterrent effect. As the U.S. seeks to shape geographical regions during peacetime operations, our model indicates that the U.S. should build strong diplomatic ties with the regional nations. A stronger diplomatic tie results in a greater likelihood that a nation will choose to join the U.S. alliance. When the focus of the U.S. effort shifts to

deterrence operations in the Phase 1 environment, the U.S. should act quickly to build its diplomatic alliance and build force presence. At times, the model demonstrated that the U.S. should transition to Phase 2, and seize the initiative, even with a diplomatic and force advantage over the enemy.

We observe that the number and strength of the regional nations affect the probability of deterrence, and demonstrates the model's sensitivity to these input parameters. In our model, we define a nation's strength by the quality of its military and the size of its economy. We observe that as the number of nations in a player's alliance increases, so does its ability to effectively deter. More importantly, stronger nations in a player's alliance prove to be more effective at deescalating regional tension. In our study, Indonesia and Taiwan represent the strongest nations in terms of military strength and economic power.

## B. ASSUMPTIONS AND LIMITATIONS

Players act simultaneously and must act on a strategy in its pure strategy set. It is conceivable, in a real-world scenario, that a player may desire to observe the other player's action before choosing its own action. However, each player must take an action during each round.

Once a player increases its military forces, the player is unable to decrease them. We add this assumption to ensure that once the Markov game leaves a state, it will not return to that state, which adds tractability to the model and allows us to solve recursively. Within the construct of our model, the choice of military forces is simplified into the allocation of forces, which include the CSG. Blue's unit of force represents a CSG. Each unit of force for the Red player is considered to have the military striking power of one CSG. If one player decides to transition to Phase 2, while the other player chooses to transition to Phase 0, we assume that the game transitions to Phase 0 and ends.

At the beginning of the Markov game, all regional nations are neutral. The active players strengthen their regional position by pursuing diplomatic alliances with the nations and deploying forces to the operating area. Once a nation joins the alliance of a player, it remains faithful to the alliance for the remainder of the game.

One of our model's limitations is the lack of subject matter expert assessment for the input parameters, specifically, the economic payoff for Phase 0 and Phase 2. To demonstrate the model, we use equations (3.1) through (3.8) to calculate these payoffs.

Allowing only a single action for each player during a round provides another limitation. In a given move, a player may wish to conduct a military move and a diplomatic move, or several of each, which we do not allow.

## C. MARKOV GAME VERSUS WARGAME

We compare two approaches used to assess the CSG's deterrence value: the wargame in Atkin et al. (2017) and the Markov game model in this thesis. For each approach, we examine the active players, allowable moves, and the game's output, and discuss a few pros and cons of each method.

The wargame is designed as a hybrid game, containing a mix of both closed and open aspects. Each player is a human in the loop, making active decisions and learning during gameplay. The U.S. and China make simultaneous moves, without the knowledge of what action the other player chooses. A seminar style approach is used to represent the regional nations, where a group of players collectively make decisions for each regional nation. However, this design can fail if there is a lack of subject matter experts representing the game's players. For example, if the regional nation panel only consists of military officers from the Philippines, they may not accurately reflect political decisions and/or actions taken by Vietnam.

In the mathematical model, only the main players are considered active decision makers, whereas the other nations in the region are modeled by random events. The regional nation's decision to join a player's alliance is based on a predetermined diplomatic tie value, which remains unchanged during the game. The model limits the actions of each player to those strategies available in the respective pure strategy set. While this construct limits the state space and enhances solvability, it restricts the ability to fully capture all actions that may cause the environment to transition out of Phase 1.

During each round of the wargame, the main players make a diplomatic move and a military move. The main players have an unrestricted operating budget, but play the game to minimize their cost to achieve specific country objectives. Additionally, the players are unrestricted in the type and number of forces they deploy into the South China Sea. Although not realistic, it allows the players to operate freely without restricting their decision-making process. The Markov game only allows a single choice for each player during the round, either a diplomatic move, a military move, or transition to Phase 0 or Phase 2. Both game approaches restrict a player's ability to take all necessary steps during a round to achieve respective country objectives.

The wargame results are mostly qualitative, capturing player actions, regional influence, and post-wargame survey results. The mathematical model provides quantitative results, such as the probability of deterrence, the player's pure strategy sets, and the optimal mixed strategies. While the wargame's results provide broader insight into the problem, the results are more difficult to analyze in an objective manner. The results of our wargame are not repeatable. In other words, if we were to repeat the wargame, we would be presented with different results. The quantitative results of the model are easier to aggregate and compare, but do not provide the same breadth of results as the wargame. The model results are repeatable. Given the same input parameters, our model will produce the same results.

## D. FUTURE RESEARCH DIRECTIONS

Our case study uses open source data and subjective assessment to define the input values. Subject matter expert opinion or intelligence estimates could provide better resources to assess model parameters. Additionally, our model assumes that both players simultaneously make decisions without knowing the other's move. It would be interesting to assess the value of intelligence, if one player learns about the other player's move before deciding his own move. Another possible extension is to allow three or more active players in the game.

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